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Design of a production process to enhance optical performance of 3ω optics

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ABSTRACT

Using the Phoenix pre-production conditioning facility we have shown that raster scanning of 3ω optics using a XeF excimer laser and mitigation of the resultant damage sites with a CO_2 laser can enhance their optical damage resistance. Several large-scale (43 cm x 43 cm) optics have been processed in this facility. A production facility capable of processing several large optics a week has been designed based on our experience in the pre-production facility. The facility will be equipped with UV conditioning lasers - 351-nm XeF excimer lasers operating at 100 Hz and 23 ns. The facility will also include a CO_2 laser for damage mitigation, an optics stage for raster scanning large-scale optics, a damage mapping system (DMS) that images large-scale optics and can detect damage sites or precursors as small as ≈15 µm, and two microscopes to image damage sites with ≈5 µm resolution. The optics will be handled in a class 100 clean room, within the facility that will be maintained at class 1000.

1. INTRODUCTION

Over the last several years we have developed techniques using small-beam raster scanning to laser-condition fused silica optics to increase their damage threshold. [1] Further, we showed that CO_2 lasers could be used to mitigate and stabilize damage sites while still on the order of a few tens of microns in size, thereby greatly increasing the lifetime of an optic through reuse. [2] With construction of the National Ignition Facility proceeding, the ability to process full-scale 43 cm x 43 cm optics is required.

We have constructed a pre-production facility called Phoenix where we have demonstrated the off-line conditioning process. The conditioning and mitigation process is a three-step process conducted in an off-line facility. Step one is to photograph the optic to record surface defects. The raster step, shown schematically in Figure 1, involves scanning a UV laser across the entire surface of the optic, starting at a low fluence and repeated in steps of increasing fluence. The optic is photographed again after each raster step to record changes in the damage condition. Any new surface damage or changed defects are then mitigated using a CO_2 laser, shown in Figure 1.

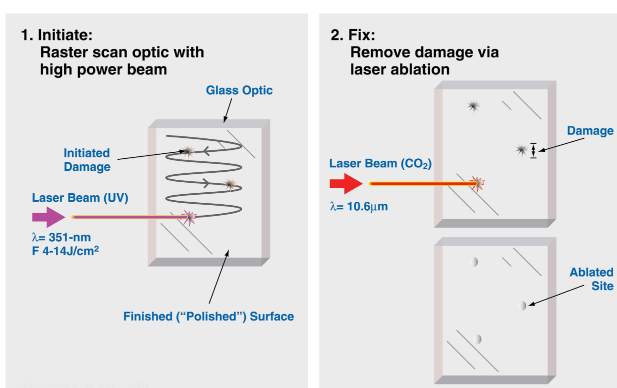

Figure 1: Schematic showing the raster scan and mitigation steps.

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A schematic layout of the equipment required in the process is shown in Figure 2. A conditioning and mitigation facility consists of a UV conditioning laser, a beam delivery system to produce the appropriate fluence on the optic to be scanned, an optics translation stage, an IR mitigation laser and an imaging system to acquire images of the optic and to examine defects on the surface of the optic. The rest of this paper discusses the various components in detail showing the design criteria used to develop a conceptual design for a production facility.

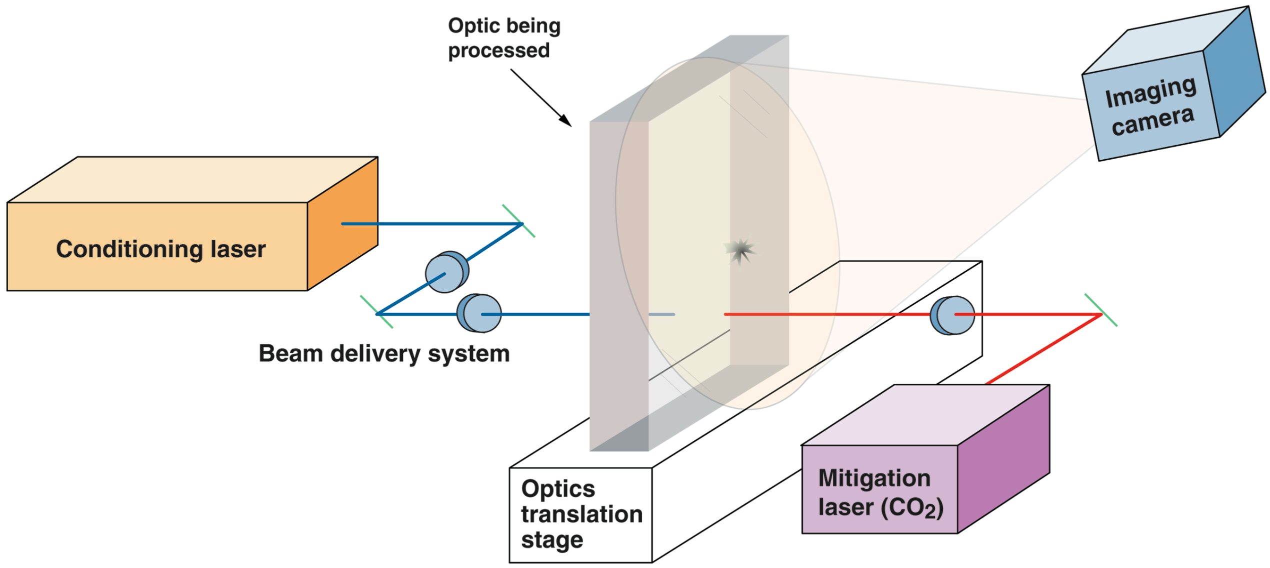

Figure 2: Layout of the equipment required for the conditioning and mitigation process.

2. CONDITIONING LASER

We have used two types of UV conditioning lasers – an XeF excimer laser and a frequency tripled Nd:YAG laser. A comparison of the attributes of the types of systems can be found elsewhere in these proceedings. [3] The laser of choice, the 351-nm, XeF excimer laser, can be configured with two types of cavities – a stable resonator cavity and an unstable resonator cavity. Both types of laser cavities produce a rectangular beam. Figure 3 shows the beam profiles from both cavities.

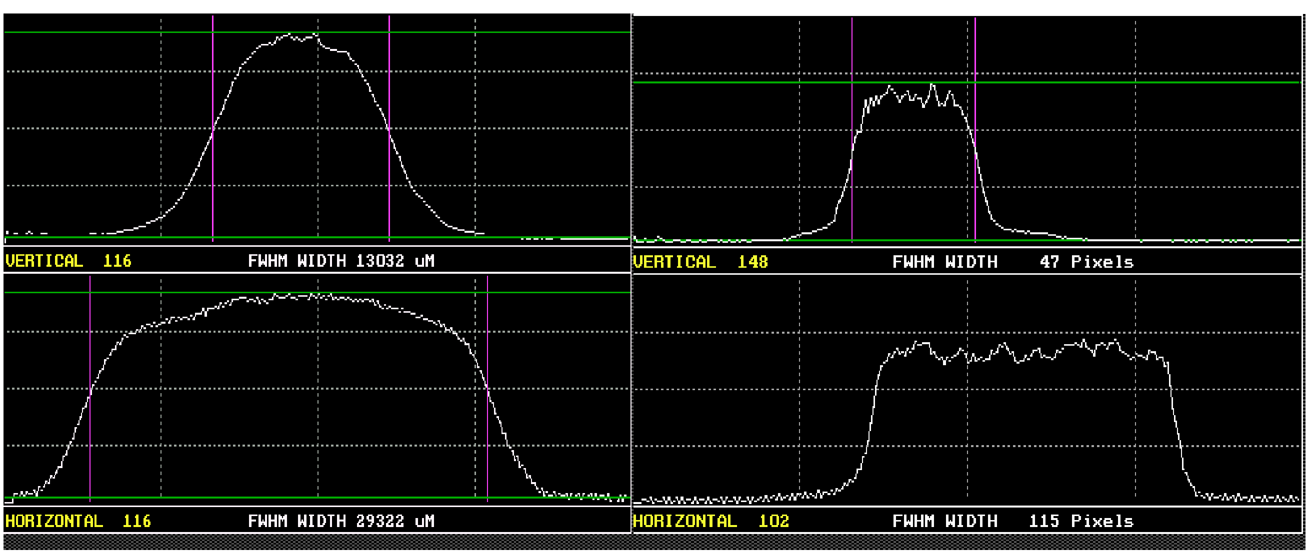

Figure 3: Beam profiles from the stable (left images) and unstable (right images) resonator cavities in a XeF excimer laser. These data are courtesy of Light Machinery Inc.

The profile from the unstable resonator is a top hat profile in both the horizontal and vertical directions, which is preferred, while the beam from the stable resonator is closer to a Gaussian in the vertical direction and a quasi-top hat in the vertical direction. Another advantage of the unstable resonator cavity is the x10 reduced beam divergence. The beam divergence of the stable resonator is 1 mrad x3 mrad while that for the unstable resonator is <0.3 mrad. This allows for a better depth of field of the imaged beam, which in turn allows for both optical surfaces to be processed simultaneously. The large divergence of the stable resonator cavity produces a beam with a short depth of focus. [3]

3. BEAM DELIVERY SYSTEM

In order to achieve the UV fluences required for the conditioning of the optics the conditioning laser beam must be reduced considerably in size. This can be achieved using a dynamic optical image relay system shown in Figure 4. The image relay technique is particularly applicable for the unstable resonator cavity, since the beam at the laser output is already in the top-hat shape required for efficient raster scanning. Optics are radiated by several fluences during the conditioning process. Different fluences are achieved on the surface of the optic by using different beam sizes, which are created by moving or replacing the three lenses in the beam delivery system. This procedure uses the available laser radiation with maximum efficiency, eschewing the use of a beam attenuator commonly used for changing the fluence on the optic.

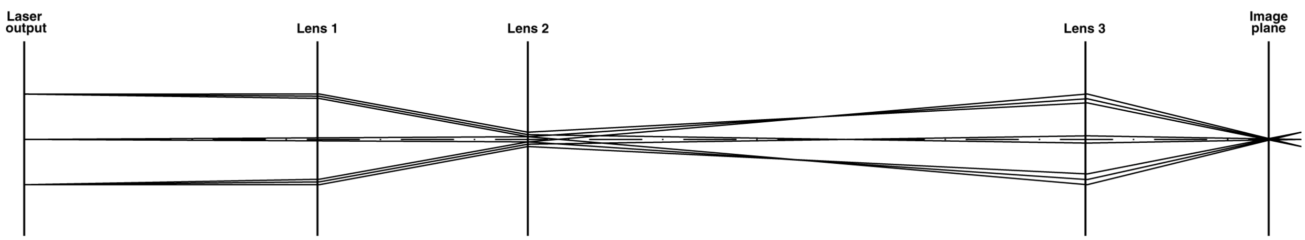

Figure 4: Schematic diagram of the beam delivery system to be used to image the output of the laser on the optic.

4. MITIGATION LASER

Previous work has shown that a 10.6 µm, CO_2 laser can be used to mitigate laser-initiated damage. [2] The site that is produced using the CO_2 laser to ablate and melt the damaged material and "heal" the surrounding area has been shown to be resistant to further damage upon repeated exposure to 351 nm radiation. In addition to being resistant to further damage, mitigated sites must not produce downstream intensification that might damage other optics in the system. In order to keep downstream intensification to a minimum it is desirable to keep the diameter and the depth of the mitigated site as small as possible, while fully removing the damaged material. The parameters of the CO_2 laser determine the morphology of the mitigated site.

Figure 6 shows an example of a mitigated site created using a pulsed CO_2 laser with 50 µs quasi Gaussian temporal pulses, a quasi flat top spatial beam, 2 J/pulse maximum energy and 1.5 Hz repetition rate. The site was produced in fused silica with the beam fluence set to 28 J/cm^2 and 10 pulses were fired at the same location. The lower half of the figure shows a single line profile. The figure shows that the site has sharply sloping walls and a quasi-flat base. Downstream intensification from such sites has been found to be small.

Another type of CO_2 laser used in the pre-production facility is a 50 W CW laser. The use of a shutter with this laser allows for the adjustment of the energy and pulse length of the pulses incident upon the optic. These two types of mitigation lasers are presently being investigated as the potential laser of choice for mitigation in the production system. A model of the processes that occur during mitigation is being developed [4] that is guiding the choice of energy/pulse and pulse duration of the CO_2 laser required to mitigate different types of sites. Shorter pulse duration lasers with enough energy/pulse can heat the fused silica locally to a high enough temperature to cause ablation but not much melting. Longer pulse duration lasers can heat a large enough volume to cause some melting as well. The relative importance of melting vs. ablation is being studied for different types of damage sites.

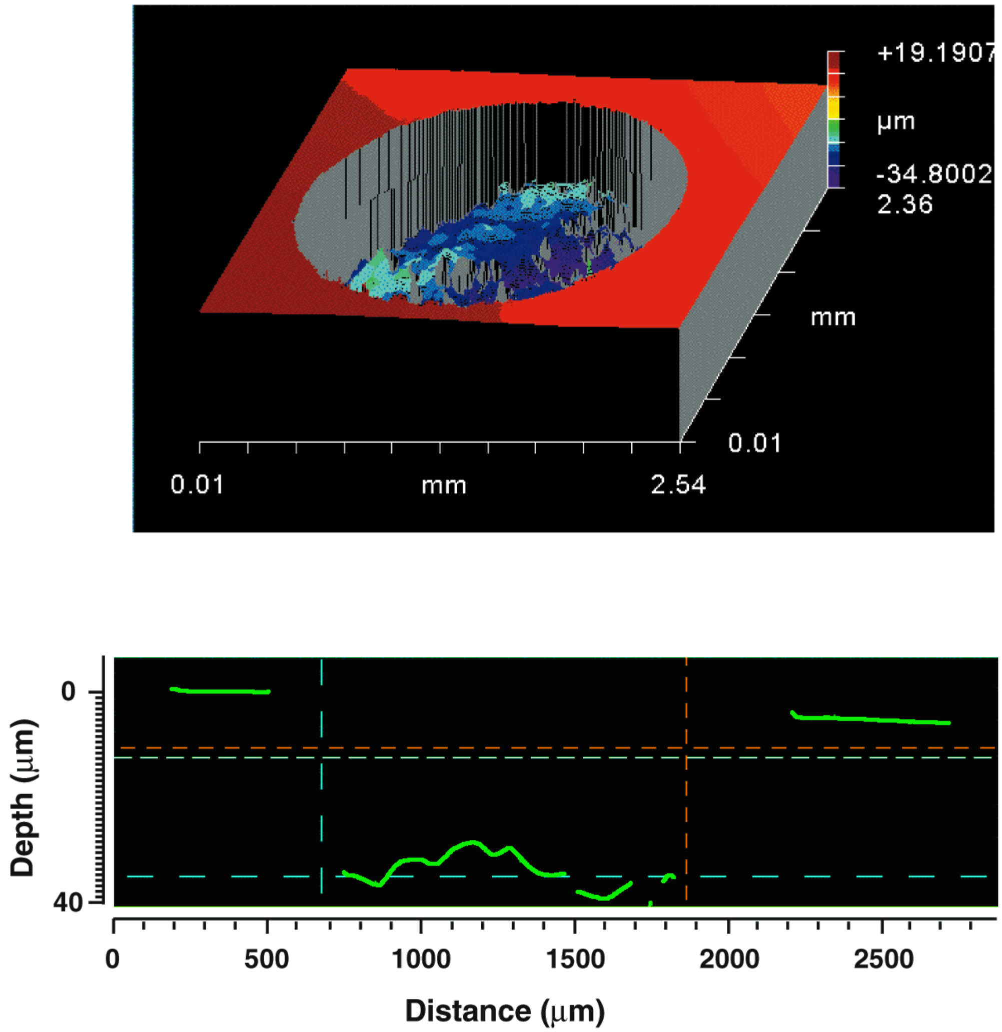

Figure 5: Typical mitigated site profile produced using a pulsed CO_2 laser.

5. IMAGING SYSTEM

Defects that are to be mitigated are detected using the imaging system. This system should thus be capable of detecting small defects. Our system, shown schematically in Figure 6 can detect defects as small as 20 µm in diameter. It consists of a system of edge illumination of the optic and an imaging camera.

We have chosen to use edge illumination with a fiber light bar using white halogen light or a series of diodes with monochromatic infrared radiation. There are a couple of advantages to using the IR diodes. The first is that with the IR illumination it is possible to eliminate background room light through the use of filters, allowing the room lights to stay on during imaging. The second advantage stems from the fact that color CCD cameras cost less than the “scientific” black and white cameras. These color CCD cameras use four pixels, each with blue, green and red filters to create a color super pixel. The transmission of these filters, shown in Figure 7, varies with wavelength in the visible region. Thus white light illumination would produce a different response from the different pixels of the CCD, depending upon which filter covered the pixel. This would in turn make defects of the same size appear with different intensities in the resulting image. However, the IR diodes that we use emit light at 810 nm. A glance at Figure 7 shows that the transmission of all three color filters is essentially the same at 810 nm. In addition, the CCD sensor is more sensitive to 810 nm light than visible light, improving the detection of defects illuminated using IR radiation.

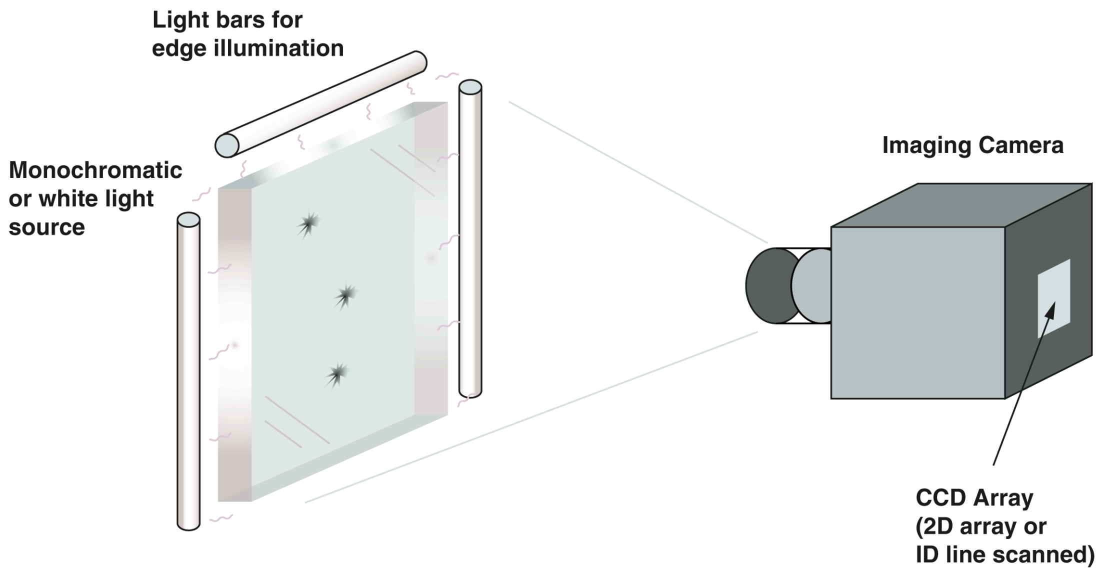

Figure 6: Schematic diagram of the imaging system capable of detecting defects as small as 20 µm in diameter.

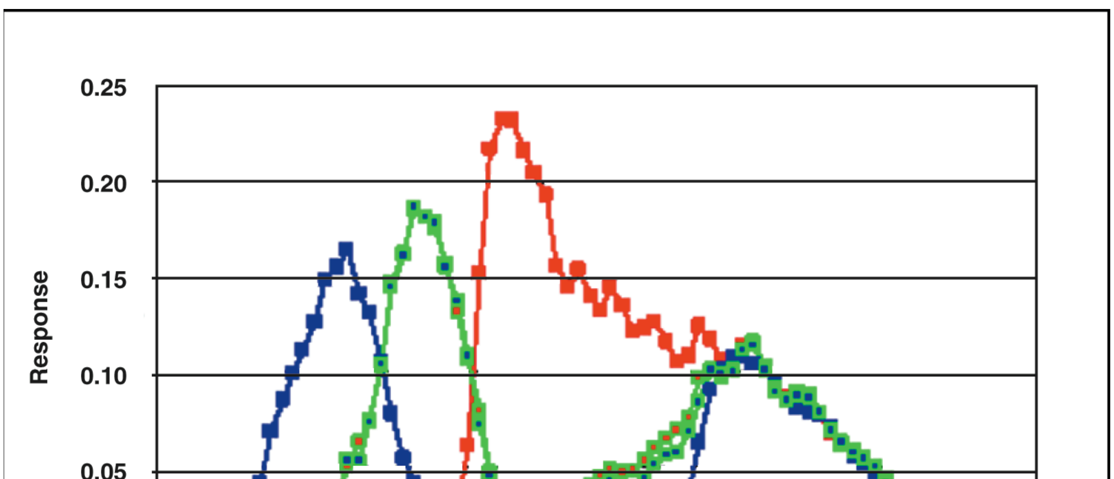

Figure 7: Spectral response of the three color CCD filters.

The imaging camera can be either a two-dimensional array CCD camera or a linear scanning camera since the optic can be held stationary for long periods of time. The linear array was initially chosen because of the larger number of pixels available along one axis providing the promise of better resolution. The advantage of using an array camera is that the image acquisition time is considerably shorter. For similar resolution images the 2D array CCD takes about 1 minute to acquire an image of a 43 cm x 43 cm optic while the scanning camera takes about 30 minutes. Figure 8 shows images acquired using the 4000x4000 pixel CCD camera and the 8000x1 pixel line scan camera. The 16-bit resolution of the 16M pixel array camera provides considerably greater defect detection, even though the raw resolution of the camera is smaller than that for the line scan camera.

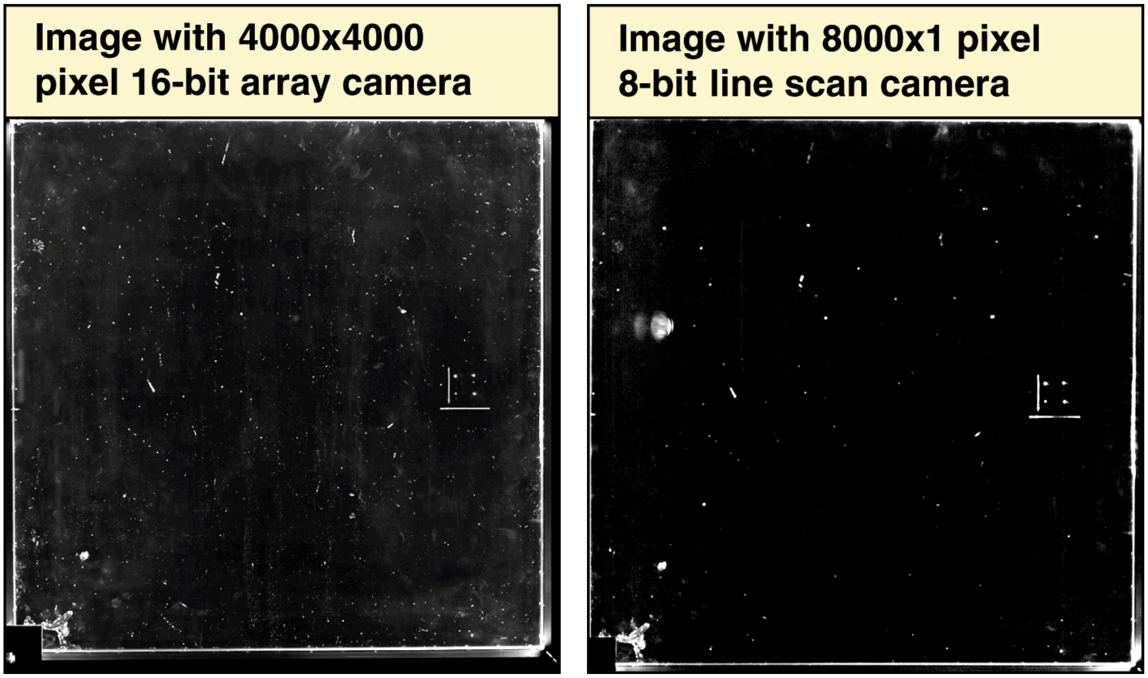

Figure 8: Comparison images of a test optic with the 4000x4000 pixel camera and the 8000x1 pixel camera.

Defects located in the images of the full optic as shown in Figure 8 are then imaged in greater detail using a long working distance microscope. This microscope provides a resolution ≈1 μm.

6. CONCLUSION

Using the pre-production facility, Phoenix, for the conditioning and mitigation of optics we have examined the various components of a facility capable of processing several optics per week. This has led us to a conceptual design of a production facility. There are several design considerations that must be taken into account to translate this concept design into a facility design.

The optics must be handled in a clean environment to eliminate particles on the optic during processing. Particles deposited on the optic during scanning with the conditioning laser could lead to additional damage of the surface. Thus we will build a class 100 room to handle the optics while the rest of the equipment such as the lasers will be in the facility designed for class 1000 operation. The optics system must be stable with minimal vibration to prevent beam wander during raster scans.

The size of the optics to be processed determines the diagnostic system (imaging camera) requirements. The size of the optics stage to move the optic during raster scanning is also determined by the size of the optics. Finally, the throughput of the system is determined by the laser average power, the optics stage speed, the diagnostics and the level of automation.

ACKNOWLEDGEMENT

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REFERENCES

1. Raymond M. Brusasco, Bernie M. Penetrante, John E. Peterson, Stephen M. Maricle, Joseph A. Menapace, "UV laser conditioning for the reduction of 351-nm damage initiation in fused silica," in *Laser-Induced*

Damage in Optical Materials: 2001, Gregory J. Exarhos, Arthur H. Guenther, Keith Lewis, M. J. Soileau and Christopher J. Stolz, eds. SPIE Vol. **4679**, 48-55 (2002).

2. Raymond M. Brusasco, Bernie M. Penetrante, James A. Butler and Lawrence W. Hrubesh, "Localized CO_2 laser treatment for mitigation of 351 nm damage growth on fused silica," in *Laser-Induced Damage in Optical Materials: 2001*, Gregory J. Exarhos, Arthur H. Guenther, Keith Lewis, M. J. Soileau and Christopher J. Stolz, eds. SPIE Vol. **4679**, 40-47 (2002).
3. Rahul R. Prasad, Justin R. Bruere, John Peterson, John Halpin, Michael Borden and Richard P. Hackel, "Enhanced performance of large 3ω optics using UV and IR lasers," elsewhere in these proceedings.
4. Michael D. Feit and Alexander M. Rubinchek, elsewhere in these proceedings.